Nutrition and Fertilization: PPM vs. Millimoles

Eric van Steenis
Nursery Extension Services, B.C. Ministry of Forests

Introduction

Current convention in fertilizer application familiar to most of us is PPM or "parts per million". It is a calculation based on the weight of one substance in relation to another with which it is mixed or associated. An example of one (1) PPM would be 1 gram/1000 kilograms (1 gram/1,000,000 grams).

Thus, a PPM of anything is equal to one part of it (by weight) to one million parts (by weight) of something else. In our case it is usually grams of a particular nutrient relative to grams of water. Water is particularly useful in this case because it weighs 1 gram/milliliter or 1 kilogram per liter. Hence 1 gram of a nutrient dissolved in 1000 liters of water equals 1 PPM (1g/1000L x 1000g/L = 1g/1,000,000g).

From the grower's perspective this convention works fine because it relates directly to the fertilizer mixing process, which requires weighing out specific fertilizer amounts and adding them to water. Hence, thinking of feeding nutrients in ppm sized portions keeps things in perspective. Moving onward, one would assume that 1 PPM of calcium and 1 PPM of magnesium mixed together equals a 1:1 Ca:Mg feeding regime. This is true on a weight basis but lets look at it from the plant's perspective.

Millimoles...

Plants take up nutrients on an individual ion, atom, or molecule basis, i.e. one calcium or magnesium atom at a time. Since these individual entities are so extremely small a very large standardized quantity was devised to allow their mass to be more easily measured and compared. The "mole" was chosen. A "mole" is a standardized quantity = 6.02×10^{23} items, just as a "dozen" is a standardized quantity = 12 items. "Milli" means 1/1000th hence a millimole (mmole) is 1/1000th of a mole.

To help grasp the concept better one must revisit the periodic table of elements. Here, one finds that calcium and magnesium have atomic weights of 40 and 24 grams, respectively. This means that 1 mole of calcium atoms weighs 40 grams, and 1 mole of magnesium atoms weighs 24 grams. It thus follows that calcium atoms are 1.67 times as heavy as magnesium atoms! So when a grower is feeding equal proportions of Ca and Mg on a PPM (weight) basis he/she is actually feeding 1.67 times as many Mg atoms as Ca atoms! In a similar vein, if a farm has a lonely one pound chicken roaming around among 1000 (1000lb each) steers, then the concentration of chickens to steers is 1/1000. On a weight basis the farm would have one pound of chickens per million pounds of steers, or 1 ppm of chickens.

When attempting to sort out competition effects, ionic balance, or just set up nutrient feeding ratios, the above can have serious implications. A way to address this is to look at nutrient application rates on a concentration instead of a weight basis, i.e. use relative molar ratios of nutrients. Concentration is normally expressed on a per liter basis, hence a solution containing 40 grams of calcium/liter is a 1 molar solution. Similarly, a solution containing 24 grams of magnesium/liter is also a 1 molar solution. Both solutions have the same nutrient concentration, although containing different weights of the respective nutrients.

Molecules...

Another difficulty with PPM can arise when the nutrient is taken up as part of a larger molecule or ion. This is because molecular weight is the sum of constituent atomic weights. Let's take for example silicon (Si), taken up by the plant in the form of $Si0_2$.

In Table 1, part of the weight contained in the "ppm" application of $Si0_2$ is the pair of oxygen atoms. Consequently, it takes a lower number of $Si0_2$ molecules to make up a 100 ppm feed. When feeding on a concentration basis (4 mmoles), the number of Si atoms supplied is the same in both regimes (Si and $Si0_2$). It takes 1 mole of silicon and 2 moles of oxygen to make 1 mole of $Si0_2$. The atomic weights of silicon and oxygen are 28 g/mole and 16 g/mole respectively, hence the total of 60 g/mole.

Table 1: Silicon application rate comparison

Form	Grams/mole*	Application rate	Actual Silicon fed/liter H_2O
Si	28	100 ppm	0.100 grams (3.57 mmoles)
Si02	60	100 ppm	0.047 grams (1.67 mmoles)
Si	28	4 mmoles	0.112 grams
Si02	60	4 mmoles	0.112 grams

* obtained from periodic table

To prevent confusion and/or improper application rates, it is important to specify the exact form of the nutrient that the fertilizer schedule refers to. Similar misunderstandings can come about when working with P_20_5 vs P, or K_20 vs K application rates.

Conversion of PPM to Millimoles... use the following formula...

$$\frac{\text{PPM Nutrient feed}}{\text{Atomic or Molecular Weight of Nutrient}} = \text{mmoles of nutrient/liter } H_2O$$

e.g. $$\frac{\text{PPM Calcium feed}}{40} = \text{mmoles of calcium/liter } H_2O$$

If the nutrient is supplied as part of a molecule, multiply by the number of nutrient atoms in the molecule.

e.g. $$\frac{\text{PPM } P_2O_5 \text{ feed}}{\text{MW of } P_2O_5\text{**}} \times 2 = \text{mmoles of phosphorus (P)/liter } H_2O$$

** molecular weight of P_2O_5 = 142 grams

Table 2 shows the difference between the two conventions. The ppm column tells us that for every 100 grams of N supplied the solution is supplying 21.8 grams of P, 81.3 grams of K, 43.8 grams of Ca, etc.

The atomic ratio column is basically the ppm column, but adjusted so that quantities of nutrient elements are set relative to a standard of 100 nitrogen atoms to reduce confusion with decimal places and to see the relationships more clearly. It tells us that for every 100 N atoms supplied the nutrient solution supplies 10 P atoms, 29 K atoms, 15 Ca atoms, etc.

Working with ppm one might assume that the N/P feeding ratio is approximately 5:1 whereas from the plant's perspective on an atomic basis, it

Table 2. Sample conversion of PPM to mmoles using a general conifer seedling grower formulation for peat-based container culture (soluble application).

Element	Symbol	PPM	Mmoles (per liter)	Atomic ratio (per 100 N atoms)
Nitrogen	N	100	7.14	100
Phosphorus	P	21.8	0.70	10
Potassium	K	81.3	2.08	29
Calcium	Ca	43.8	1.09	15
Magnesium	Mg	15.1	0.62	9
Sulphur	S	19.5	0.61	9
Iron	Fe	1.78	0.0319	0.45
Zinc	Zn	0.25	0.0038	0.05
Copper	Cu	0.40	0.0063	0.09
Manganese	Mn	0.25	0.0045	0.06
Boron	B	0.28	0.0259	0.36
Molybdenum	Mo	0.01	0.0001	0.002

is actually 10:1. This is because phosphorus atoms weigh much more than nitrogen atoms. Similarly, the N/Zn ratio is 400:1 on a weight basis and 2000:1 on a concentration basis.

Table 3 compares concentrations of nutrients at a constant 100 ppm feeding rate. It shows how the atomic weights of the various elements, as well as the form in which they are supplied or taken up, affect the actual amounts available to the plants.

The choice of convention is up to the grower. To make calculations easier and less prone to error a simple spreadsheet can be made up using conventional software.

Table 3. Conversion of 100 PPM to mmoles for some plant nutrient elements and compounds

Element	Compound	Atomic or Molecular Weight	Symbol	Charge	Millimoles @ 100 ppm	Millimoles of nutrient element	ppm of nutrient element
Nitrogen		14.0	N		7.14	7.14	100.0
	Nitrate	62.0	NO_3	-	1.61	1.61	22.5
	Ammonium	18.0	NH_4	+	5.56	5.56	77.9
Phosphorus		31.0	P		3.22	3.22	100.0
	Phosphate	97.0	H_2PO_4	-	1.03	1.03	32.0
	Phosphate	96.0	HPO_4	2-	1.04	1.04	32.3
	fert. equiv.	142.0	P_2O_5		0.70	1.41	43.8
Potassium		39.1	K	+	2.56	2.56	100.0
	fert. equiv.	94.2	K_2O		1.06	2.12	82.8
Calcium		40.1	Ca	2+	2.49	2.49	100.0
Magnesium		24.3	Mg	2+	4.12	4.12	100.0
Sulphur		32.1	S		3.12	3.12	100.0
	Sulphate	96.0	SO_4	2-	1.04	1.04	33.3
Sodium		23.0	Na	+	4.35	4.35	100.0
Chlorine		35.4	Cl	-	2.82	2.82	100.0
Iron		55.8	Fe	2+	1.79	1.79	100.0
		55.8	Fe	3+	1.79	1.79	100.0
	Chelates	343.5	Fe EDTA		0.29	0.29	16.2
		387.7	Fe DTPA		0.26	0.26	14.5
		614.0	Fe EDDHA		0.16	0.16	8.9
Zinc		65.4	Zn	2+	1.53	1.53	100.0
	ZincHydroxide	82.4	ZnOH	+	1.21	1.21	79.1
	ZincChloride	100.8	ZnCl	+	0.99	0.99	64.7
	Chelates	353.5	Zn EDTA		0.28	0.28	18.3
Copper		63.5	Cu	2+	1.57	1.57	100.0
	CopperHydroxide	80.5	CuOH	+	1.24	1.24	79.0
	Chelates	349.5	Cu EDTA		0.29	0.29	18.5
Molybdenum		95.9	Mo		1.04	1.04	100.0
	Molybdate	159.9	MoO_4	2-	0.63	0.63	60.6
Manganese		54.9	Mn	2+	1.82	1.82	100.0
	Chelates	342.3	Mn EDTA		0.29	0.29	15.9
Boron		10.8	B		9.26	9.26	100.0
	Borate	61.8	H_3BO_3		1.62	1.62	17.5

The following spreadsheets are constructed in Microsoft Excel 5.0. They basically allow one to formulate fertilizer programs without having to worry about doing the math. The fertilizers listed are commonly used in B.C. forest nurseries.

To use the sheet first set the appropriate injector ratio and concentrate mixing bin size. Then input desired fertilizer amounts in the g/1000L (or ounces/100USG) column and watch the corresponding fertilizer regime in ppm and mmoles appear in the table on the right. The sheet will also indicate how much bulk fertilizer to add to the concentrate bin(s) to effect the nutrient regime chosen. Be aware that you may not be able to mix all fertilizers in one concentrate bin.

FERTILIZER Eric van Steenis July 18, 1997 Version	Rate in grams/ 1000L @ sprinkler	Kg FERT/ 200 Ltr Concentrate @ 1: 200 Injection Ratio	FINAL NUTRIENT REGIME IN X	: PPM	Feeding Rate Per 100 N : mmoles	atoms
PlantP 12-17-29F	200	= 8	NO3-N	75.0	5.36	75
PlantP 20-8-20F	0	= 0	NH4-N	24.9	1.78	25
PP*NO3* 20-8-20F	200	= 8	N (t)	100.0	7.14	100
PlantP 8-20-30F	0	= 0	P	21.8	0.70	10
PlantP 11-41-8F	0	= 0	K	81.3	2.08	29
PlantP 20-20-20	0	= 0	Ca	43.8	1.09	15
Excel 21-5-20	0	= 0	Mg	15.1	0.62	9
Excel 15-5-15	0	= 0	S	19.5	0.61	9
Excel Mg(NO3)2	0	= 0	Fe	1.78	0.0319	0.45
Excel Ca(NO3)2	0	= 0	Mn	0.25	0.0045	0.06
Ca(NO3)2 15.5-0-0	232	= 9.28	Zn	0.25	0.0038	0.05
KNO3 13-0-46	0	= 0	Cu	0.40	0.0063	0.09
NH4NO3 34-0-0	0	= 0	B	0.28	0.0259	0.36
KH2PO4 0-52-34	0	= 0	Mo	0.01	0.0001	0.002
MgSO4	150	= 6	Si	0.0	0.00	0.00
K2SO4 0-0-50	0	= 0	HCO3	0.0	0.00	0.00
(NH4)2SO4 21-0-0	0	= 0	CaCO3	0.0	0.00	0.00
(NH4)2HPO4 21-53-0	0	= 0	Na	0.0	0.00	0.00
ZnSO4 35%	0	= 0.000				
CuSO4 24%	0	= 0.000				
FeSO4 21%	0	= 0.000				
Fe Chelate 13.2%	0	= 0.000	P2O5	50.0	0.35	
Plant Prod Micro	0	= 0.000	K2O	98.0	1.04	
Na Molybdate	0	= 0.000				
STEM	0	= 0.000				
SOLUBOR	0	= 0.000	H+	0.00	0.00	
H3PO4 85% SG1.75	0	ml = 0.000 Ltr				
H2SO4 100% UN1830	0	ml = 0.000 Ltr				
H2SO4 36% SG1.265	0	ml = 0.000 Ltr	Aquagro:	0.0	Active Ingredient	
HNO3acid67%SG1.4078	0	ml = 0.000 Ltr	2000L		Only	
Silicon K2SiO2	0	ml = 0.000 Ltr				
Aquagro 2000L (85%)	0	ml = 0.000 Ltr				

FERTILIZER Eric van Steenis May 15, '97 version	Rate in g/1000l			Kg FERT/ 200 Ltr concentrate @ 1 : 200 injection ratio	FINAL NUTRIENT REGIME X	ppm	:	Feeding Rate Per 100 N mmoles	atoms
TANK "A"									
Ca(NO3)2 15.5-0-0	0		=	0	NO3-N	0.0	:	0.00	####
CaCl2	0		=	0	NH4-N	0.0	:	0.00	####
Mg(NO3)2	0		=	0					
KNO3 13-0-46	0		=	0	N (t)	0.0	:	0.00	####
NH4NO3 34-0-0	0		=	0	P	0.0	:	0.00	####
Fe DTPA 7%	0		=	0	K	0.0	:	0.00	####
TANK "B"					Ca	0.0	:	0.00	####
KNO3 13-0-46	0		=	0	Mg	0.0	:	0.00	####
KH2PO4 0-52-34	0		=	0	SO4-S	0.0	:	0.00	####
K2SO4 0-0-50	0		=	0	Cl -1	0.0	:	0.00	####
MgSO4-7H2O	0		=	0				0	
MgSO4-1H2O	0		=	0	Na	0.0	:	0.00	####
Mg EDTA 5.8%	0		=	0	Si	0.0	:	0.00	####
KCl 0-0-62	0		=	0					
(NH4)2SO4 21-0-0	0		=	0	P2O5	0.0	:	0.00	
(NH4)2HPO4 21-53-0	0		=	0	K2O	0.0	:	0.00	
(NH4)H2PO4 12-61-0	0		=	0					
Silicon/H4SiO4	0		=	0	HCO3	0.0	:	0.00	####
					CaCO3	0.0	:	0.00	####
					EDTA	0.0	:	0.00	####
ZnSO4 35%	0		=	0.000	DTPA	0.0	:	0.00	####
CuSO4 24%	0		=	0.000					
FeSO4 21%	0		=	0.000		**ppm**		**umoles**	
MnSO4 29.5%	0		=	0.000	Fe	0.00	:	0.00	####
Fe EDTA 13.2%	0		=	0.000	Mn	0.00	:	0.00	####
Fe DTPA 7%	0		=	0.000	Zn	0.00	:	0.00	####
Cu EDTA 14%	0		=	0.000	Cu	0.00	:	0.00	####
Mn EDTA 13%	0		=	0.000	B	0.00	:	0.00	####
Zn EDTA 14%	0		=	0.000	Mo	0.00	:	0.00	####
Na Molybdate	0		=	0.000	Al	0.00	:	0.00	####
SOLUBOR	0		=	0.000					
Boric Acid (Borax)	0		=	0.000		**ppm**		**mmoles**	
Plant Prod Micro	0		=	0.000	H+	0.00	:	0.00	####
STEM	0		=	0.000	OH-	0.00	:	0.00	####
pH Adjusters						**Ionic**		**Balance**	
Ca(OH)2	0		=	0.00	-ve charges		:	0.00	
KOH	0		=	0.00	+ve charges		:	0.00	
KHCO3	0		=	0.00					
H3PO4 85% SG1.75	0	ml	=	0.00 Ltr	Calculated EC		:	0.00	umhos
H3PO4 75%	0	ml	=	0.00 Ltr	Raw water EC		:	0.00	umhos
H2SO4 100% UN1830	0	ml	=	0.00 Lt					
H2SO4 36% SG1.265	0	ml	=	0.00 Ltr	Total EC		:	0.00	umhos
HNO3acid 67%SG1.4078	0	ml	=	0.00 Ltr					

Diskettes containing the spreadsheets can be obtained from Eric van Steenis at B.C. Forest Service, 14275 96th Avenue, Surrey, B.C., V3V 7Z2 Canada.

References

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